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The Galactic and LMC Extreme Emission Line Supergiants Compared:
IUE Observations of the Henize - Carlson and Zoo Star Samples of
 Massive Supergiants

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ABSTRACT

We report on the second epoch of a study of the Henize - Carlson sample of galactic massive supergiants and a comparison between the Galactic and LMC samples. Several of the stars, notably He3-395 and S 127/LMC have very similar shell characteristics. There appears to be little difference, other than luminosity, between the LMC and Galactic samples. One star, He3-1482, has been detected with the VLA at 6 cm. The UV data is combined with IRAS and optical information

in such systems, with a compact companion illuminating the stellar wind from which its power is derived by accretion. However, in other cases like S127/LMC or S128/LMC = R127, there is reason to believe that much of the phenomenology observed in both the optical and UV is the result of an intrinsic envelope instability driving time - variable mass loss.

The optical properties of many of these stars, such as photometric and spectroscopic variability, are only poorly known. In most cases, they have been observed only photographically and at low dispersion. The original emission line object survey (ref. 7) was studied at slightly higher dispersion by Carlson and Henize (ref. 3). For most of those stars which Henize had flagged as Bep or P Cyg-like, in most cases, the emission lines dominate the optical spectra and there is little evidence for photospheric absorption, other than on P Cyg lines. The UV is the best diagnostic wavelength region for the study of dense shells in these stars, and the best indication of the extreme mass loss state in which most of these stars find themselves. There is no emission, in general, in the *IUE* spectra; rather, there are strong absorption lines which indicate that a pseudo-photosphere has formed (ref. 8) and that the spectral characteristics may be useful in determining mass loss rates.

We have previously employed the method of ultraviolet spectral types (UVST) to determine bolometric corrections, luminosities, and effective temperatures for the Magellanic Cloud stars. These have compared favorably with more detailed analyses of a few stars (ref. 9) and can be obtained without assumptions about the reddening. For the LMC and SMC stars, this is not so serious a difficulty, for the galactic stars, it is a stumbling block of considerable magnitude. The problem is that the intrinsic properties of these stars are not well known; they are in the galactic plane and consequently heavily reddened, and at large but unknown distances. Consequently, most of the clues employed in determining reddening corrections to the UV continua are lacking.

The UVST method has been tried for several of the

1. Introduction

The extreme early-type emission line supergiants of the Magellanic Clouds (ref. 1), likely among the most massive stars in the Local Group, have previously been studied as part of an extensive project with *IUE* during 1981-1983 (Ref. 2) and subsequently have been discussed by several investigators (see e.g. ref. 3). The galactic analogs of these stars, the Carlson - Henize sample (ref. 4) have been discussed (ref. 5) as part of a first survey of these stars in 1985 - 1986. The purpose of this note is two-fold. One is to present the entire Galactic sample from program OBHSS. The second is to discuss those stars in the LMC which are most similar in morphology to the UV and optical spectra of the Galactic sample.

After nearly a decade of observing these stars with *IUE*, it is clear that many of the massive supergiants are spectroscopic, as well as photometric, variables. Several appear to be members of long - period binary systems (like R66). Some, like S18/SMC, may be the primaries

stars in program OBHSS in order to test its effectiveness. For the massive stars, we have calibrated two indices for Si IV $\lambda 1400$, the $\alpha(1400)$ and $\beta(1400)$ (Shore and Brown 1987, ref. 9) for the IUE standard star sample of B2V-Ib and B5I-Ia stars. These show that the UVST can be fit quantitatively as well as by the overall appearance of the continuum. In addition, we have calibrating, using the LMC/SMC sample and galactic stars, a set of line indices for Al III, Si III, Si IV, C IV, N V, and Fe II/III features. These will be reported on elsewhere (Shore *et al.* *preprint*).

The application of the UVST method to the Magellanic Cloud supergiants makes it possible to determine the presence of dust from the strength of the 2200Å feature. In the LMC, for example, this feature is weaker than in galactic stars. A sub-group of the "Zoo" stars shows strong absorption in this feature, especially S134/LMC and S30/LMC. Several of these have subsequently been found to contain dust (using near IR measurements). This will be useful as a test of whether the dust absorption in the stellar envelope or environment in the LMC is variable with time.

2. The Henize - Carlson Sample of Galactic Supergiants

The optical descriptions by Carlson and Henize (1979) suggest that the following sample of stars will be close matches for the Magellanic Cloud supergiants, having absolute magnitudes far in excess of what is normally observed for evolved stars. In fact, in the one high dispersion optical spectroscopic follow-up to date, we (Shore *et al.* 1988, *preprint*) have found that He3 - 1482 is a mass losing star more extreme than P Cygni. It is also known to be surrounded by an emission nebula in the radio, which appears resolved at 6 cm with the VLA A-configuration.

He3-40: This star was observed in 1985 and 1986 during OBHSS. It displays only complex absorption in the SWP, with the LWP showing Mg II emission. This latter feature is unique among the sample stars, and a feature that may be variable. It will be important to re-observe this star, both to look for spectral changes in the absorption and in the P Cyg lines at Mg II, which we will be doing during 1988. The SWP spectrum is like R50 = S65/SMC

He3-365: This star is most like S22/LMC, a strong Fe II/III band star. There are no emission lines observed in the SWP camera, and archival spectra show that the shell is stable on timescales of several years. It has, however, a large optical photometric amplitude ($\Delta V = 0.^m5$) like S96/LMC = S Dor. It would be most interesting to observe this star several times, since several of the large amplitude variables appear to be binaries (Hutchings *et al.* 1987, ref. 3; Zickgraf, *et al.* 1985, ref. 11). We will be obtaining spectra in this (11th) round of IUE. The present sample of spectra serve to show that the variation is primarily in the Fe II "bands", but there is no known contemporaneous photometry of this star. The UVST is B3-4 (*S Dor-like*).

The IRAS LRS spectrum shows a very strong 10μ emission feature, accounting for the 12μ excess in the star, and a nearly flat IR continuum. It is likely that the shell of this star is dusty, perhaps as dusty as S 30/LMC.

He3-395: This star is the most variable star in the Galactic sample, based on its optical properties, but we have to date only one IUE spectrum. Carlson and Henize give this star spectral type B2Ip while the UVST is B0-1; the Fe features near Al II 1860 are among the most striking features in the spectrum. It is strikingly similar to S127/LMC = R126 Zickgraf *et al.* (ref 10) have discussed this star extensively, in the context of what it illustrates about stellar mass loss properties among the hypergiants. They argue that S127 is a very rapid rotator, and that the origin of the extreme stellar wind is that the star is virtually at the stability limit for an object of low surface gravity. The fact that, as can be seen from the comparison of the SWP images of He3-395 and S127/LMC, these two stars are very similar argues that the more detailed study of these two will be most important in determining whether the model presented for the LMC star is applicable to the one in the galaxy. The two stars are so close in spectrum morphology that either there are two rotationally unstable hypergiants in the Local Group or some other process is at work. An interesting point is that *S127/LMC is not known to be a large amplitude photometric variable*. In IRAS data, only 12μ is detected and this is quite weak.

He3-407: This star has been observed several times with IUE (see fig. 2) and shows some evidence of long-term spectrum variations. The star is moderately bright, and one for which we have a long enough database to be able to say, with another year of observation, whether the trend toward stronger absorption lines is continuing. Similar behavior has been noted for S128/LMC. The UVST is B4-5 and the spectrum is a good match for S 73/LMC. IRAS data shows the envelope is likely warm dust; there is no evidence for a companion.

He3-759: To date, the only IUE spectrum we have of this star is far too weak to be useful for anything except ruling out strong emission lines. It is a class A star, having strong He II and He I emission in the optical, and one which appears similar to S9/LMC and S131/LMC and S30/LMC = R99. However, the latter two stars show strong emission in the UV, while we presently cannot say much about He3-759. The star was not seen by IRAS.

He3-1138: To date, the only IUE spectrum we have of this star is too weak to use for anything except ruling out strong emission lines. This star is similar, both optically and in the IR, to S134/LMC = HD 38489 (ref 12). HD 38489 shows strong P Cygni profiles on the C IV and possibly N V lines, and strong C III] and Si III] emission. There is a possibility of P Cygni emission at C IV $\lambda 1550$ in SWP 28313, the only exposure we have for this star, but the S/N is very poor and the conclusions drawn from this spectrum are not trustworthy. IRAS data displays no strong evidence for a dusty or strong shell, since the IR excess is weak. It may be consistent with a strong stellar wind.

He3-1300 Strong absorption is observed at C IV 1550, Si IV is sharp and Al III is absent. The UVST is likely around O9-B0. The IR excess of the star is small, but the IRAS fluxes are poorly determined. There is a faint nebulosity associated with this star that may be contaminating the IRAS bands.

He3-1330: This star appears quite similar to S128/LMC = HDE 269858f, having a UVST of B2. The Si IV lines are well resolved, and there is also strong absorption at C IV. There are several iron absorption systems, notably near 1600 Å. The Mg II lines, in the available LWP image (LWP 8190) cannot be observed due to saturation.

He3-1482. This is the only star in the sample to be observed with virtually all wavelengths from optical through radio. Judging from its optical spectroscopy, it is one of the coolest stars in the sample. There are no strong He I lines in the spectrum, and numerous [Fe II] lines. The O I λ 8445 line, which is pumped by Ly β , is strong. Several N I lines are also observed in the near IR, and there is weak evidence for the Ca II IR triplet in emission. This is also the only star in the sample with Na I showing P Cygni profiles. The reddening is estimated to be $E(B - V) = 1.^m8$ so that $A_V = 5.^m6$. The 12 μ flux compared with the 6 cm radio data gives a spectral index of $\alpha = 0.97$, characteristic of a marginally thin stellar wind. Several of the stars have to be observed with longer exposures than we originally obtained. Recent VLA A and B configuration observations at 6 and 20 cm have shown what appears to be a small H II region (about 5 arcsec across), probably thermal, with a flux of order 2 mJy (6 cm) surrounding He3-1482. The star's optical properties indicate that it possesses an enormously strong stellar wind, with \dot{M} likely greater than P Cygni. The H II region appears to be thermal. Our observation of this star (SWP 28308) shows no very strong emission lines, but the exposure is exceedingly weak. This is an extremely important comparison object, since it is the only star in the sample that can be, and has been, observed with the VLA.

3. The Magellanic Cloud Counterparts

All of the LMC/SMC "Zoo" sample have been previously observed with IUE during programs that ended nearly a half-decade ago. Consequently, they were all obtained with the LWR and all were obtained in a relatively short interval. Due to time constraints in the first programs (CBDSS and HLESS), a number of these spectra were not optimum. To place the Galactic sample in proper context, we wish to re-observe that subset of the Large Magellanic Cloud stars which seem to have partners in the Galactic sample. We also wish to obtain better spectra of a few stars which were not well observed during the previous years of IUE and which may also be analogs of the Galactic sample, at least judging from their optical spectra.

A subset of the LMC stars has been identified as possessing dust envelopes (S65/LMC = R50, S12/LMC, S22/LMC, S73/LMC = R66, S89/LMC = R82, S127/LMC = R126, S134/LMC = HD 38489) (ref. 6). Shore and Sanduleak (ref. 2) had previously suggested that sev-

eral of these were dusty on the basis of the UV continuum distributions. In addition, several of these stars show among the highest mass loss in the "Zoo" sample; several of these stars have been flagged as being LMC analogs of the Galactic sample (Shore, *et al.* 1986). In addition, a few of the Galactic sample have strong dust signatures from IRAS data (Shore *et al.* 1988, *in preparation*). *The majority of these stars have not been observed for at least three years and it would be most useful to see whether the envelopes still have the same structure on which the current comparison is based.*

S9/LMC: This is one of the earliest stars in the Magellanic Cloud sample, and one which is similar to He3-40. There are no strong emission lines in the existing UV spectrum. The S/N in the original spectrum, though, is low and it would be useful to obtain a new set of LWP and SWP spectra to better determine the properties of this star.

S12/LMC: There is only a single spectrum for this star, which is known to show IR dust emission and strong P Cygni profiles in the optical (ref. 6; Shore and Sanduleak 1988, *in preparation* [1984 CTIO observations]).

S22/LMC This star has been observed with IUE on several occasions (there are about 6 SWP images of this

star in the archives). There is no evidence of spectroscopic or photometric variability. S22/LMC shows the most extreme emission spectrum of Fe II and [Fe II] of any star in the Zoo sample (refs. 2, 6). The star is known to have a variable shell, with some light variations also having been observed. This star's spectrum is also analogous to the deep Fe absorption systems observed in the dense shell phase of SN 1987a and of η Car.

S124/LMC: This star has only one, partially overexposed, SWP spectrum. It possesses one of the deepest Si IV doublets of any of the sample, the lines in which are well resolved, and a very strong C IV line. There is no Si III, and only weak Al III. However, the Fe II absorption is well developed.

S127/LMC This star has the strongest Al III lines of any star in the sample, and is one of the few that has been observed at high dispersion. *It is the closest spectrum in the UV, among the entire "Zoo" sample, to one of the Galactic stars, He3-395.* Zickgraf *et al.* (ref. 10) have discussed it at some length, suggesting that it may be a hypergiant on the verge of rotational destruction. If so, it is important to compare this with its Galactic counterpart. While there is currently no strong evidence for photometric or spectroscopic variability, we expect that this star may have an unstable envelope and should be re-observed.

S134/LMC: This star was sufficiently deviant in our original survey to warrant separate discussion (ref. 12). Optical photometric variability has been noted (Stahl *et al.* 1985). One of the Galactic sample, He3 - 1138, has many of the same optical properties and a detailed comparison of the two stars would be interesting.

4. Concluding Remarks

For the Galactic stars, the data is too spotty presently and too incomplete, to quantitatively assess the degree of similarity between the stars. Individual stars appear, however, to bear striking resemblances to LMC stars, although the extent of this comparative behavior is not clear. In order to study the evolution of the most massive stars in two galactic systems of very different properties, a systematic approach, with a good time baseline, is required. This is essential, since observations have demonstrated that several of the Hubble-Sandage variables, of which these stars are the galactic counterparts, are variable on timescales of about a year, while others are only variable in times of decades.

We urge continued monitoring of these stars, at all wavelengths. They cannot fail to be interesting examples of the most massive stars and their antics.

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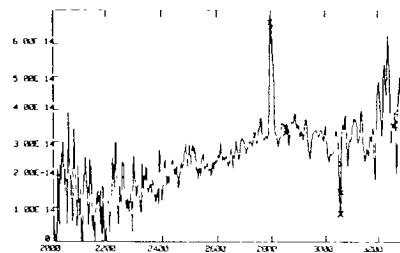


Fig. 1. He3-40 LWR 8204 (86/135.5). Note strong Mg II emission and strong 2175 absorption.

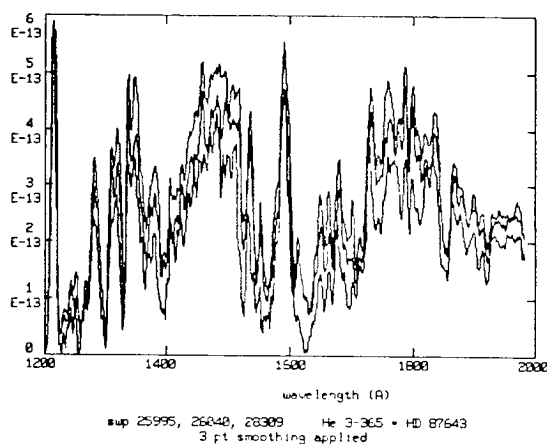


Fig. 2. Variations in He3-365 SWP spectra.

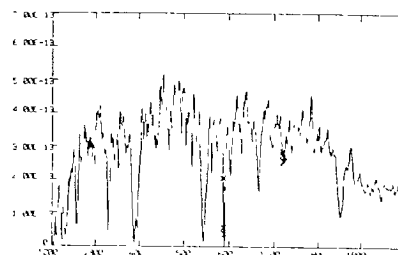


Fig. 3. He3-395 SWP 28314. Note strong absorption at Si IV and C IV/Fe II; also strong Fe II/III and Al III 1860.

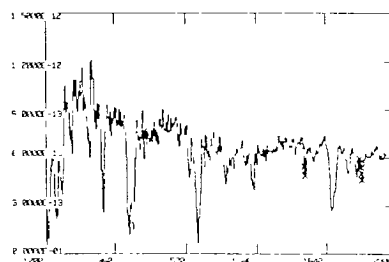


Fig. 4. S 127/LMC (SWP 16617); compare with He3-395.